

# ROADMAP

## to the Future



Strategic Mission Thrusts and  
Scientific Foundations

May 2009



Lawrence Livermore  
National Laboratory

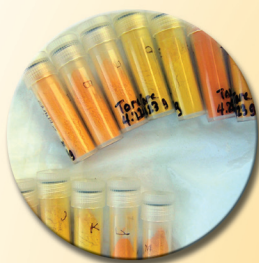
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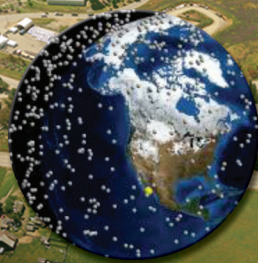
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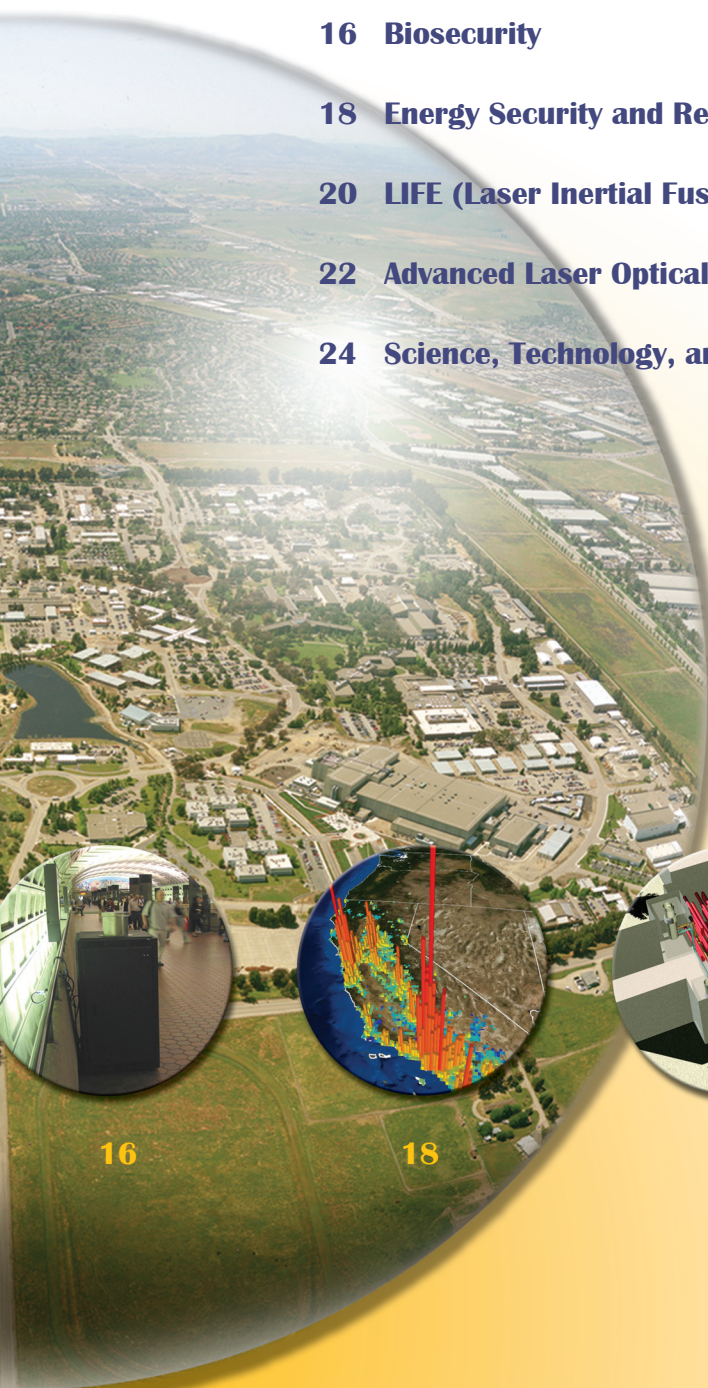
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# Game-Changing Science in the National Interest



**“In crafting the roadmap for the future, we are building on Livermore’s historic tradition of strategic thinking, innovation, and success.”**

**—Tomás Díaz de la Rubia**

**W**e have just completed version 1.0 of “Roadmap to the Future,” the Laboratory’s five-year investment strategy. The effort began with a 100-day study to take a hard look at evolving national priorities and identify areas where LLNL can place its enormous science, technology, and engineering (ST&E) capability in the service of emerging 21st-century priorities as well as our enduring missions. A tremendous amount of energy and creativity was unleashed by the teams that conducted the study. They examined seven strategic mission thrust areas as well as the ST&E foundations of the Laboratory that provide LLNL unique capabilities and underpin mission success by pushing the frontiers of key scientific and technical disciplines. The teams set “big audacious goals,” or BAGs, and devised requisite ST&E investment and business/program development strategies. The mission thrust areas, defined by Director George Miller and his senior management team, are:

- Stockpile Stewardship Science
- Nuclear Threat Elimination
- Cyber, Space, and Intelligence
- Biosecurity
- Energy Security and Regional Climate Impacts
- LIFE (Laser Inertial Fusion Energy)
- Advanced Laser Optical Systems and Applications





The BAGs aim to meet vital national needs in these mission areas and require game-changing ST&E breakthroughs to achieve success. By focusing research efforts on the BAGs, Livermore will play a leadership role in meeting the nation's and the world's most important challenges in the years to come. We are excited about the prospect. LLNL has always taken pride in translating innovative scientific concepts into solutions to meet vital mission needs. It's what we do best. Game-changing science in the national interest is the integrating theme in developing our roadmap to the future.

Game-changing breakthroughs include, for example, ST&E aimed at eliminating the threat of nuclear terrorism, providing real-time situational awareness for cybersecurity and space asset

protection, meeting future needs for clean energy while drastically shrinking the world's inventory of nuclear waste, and creating entirely new opportunities to enhance national security and explore the frontiers of nuclear science with lasers. Mission-directed projects to achieve these advances would not be possible without a strong ST&E foundation at the Laboratory. A team led by the LLNL scientific discipline associate directors identified six essential ST&E pillars: high-energy-density science, high-performance computing and simulation, materials on demand, measurement science and technology, energy manipulation, and information science. Investment strategies were developed to sustain strength in these pillars and stay at the forefront of key areas of basic science

and technology development. These strategies are an integral part of the roadmap.

This report briefly summarizes output of the 100-day study, which provides the basis for version 1.0 of the roadmap, and our path forward. We focus here on national needs, LLNL's role in meeting those needs, and leap-ahead ST&E goals and strategies. Roadmap schedules and business development considerations such as expected program growth are described in less detail. Not all goals and plans coming out of the 100-day study will be achievable as expeditiously as proposed because they are closely linked with the deliberate,

areas, we are sharpening plans and improving the alignment between ST&E and business strategies.

The Laboratory Directed Research and Development (LDRD) process at Livermore is closely coupled to the five-year roadmap. We are shifting LDRD resources to concentrate on large strategic initiatives. Significant strategic-initiative funding is being targeted at several of the mission thrust areas. All seven areas are strategic priorities of the Laboratory and will receive institutional support, and exploratory research project funding will strengthen LLNL's ST&E foundation. In addition, we have started to make investments in selected areas using funds



ongoing process of institutional investment decisions and pending federal budget decisions.

The priorities in the seven mission focus areas and ST&E foundations will benefit from institutional investments, which are constrained. How we choose to invest in new staff, R&D, technology, capital equipment, and infrastructure depends on many factors. For certain focus areas, administration and congressional priorities dictate that we act swiftly. Some focus areas have sophisticated business plans under way and leaders with a clear vision. In other

generated by the Laboratory's licensing and royalty funding stream.

It is remarkable to see the extent to which our integrating theme—**game-changing science in the national interest**—is ingrained in our thinking and pervades every thrust area. Through the innovative ideas and involvement of staff across the Laboratory, we will truly change the national, energy, and economic security landscape, and therefore the global landscape.

A handwritten signature in black ink, appearing to read 'Tomás Díaz de la Rubia'.

Tomás Díaz de la Rubia  
Chief Research and Development Officer

# Roadmap to the Future

## Meeting Important National Needs

The United States faces tremendous challenges, many of them related to our security as a nation in a world that is undergoing dramatic change. National security in the 21st century encompasses far more than traditional consideration of U.S. military might. America needs protection from unconventional threats such as use of weapons of mass destruction by terrorists and cyber attacks. Global warming looms as a threat to international order that is compounded by the increasing demand for energy worldwide. And the well-being of Americans depends on economic competitiveness in a global marketplace.

These challenges call for innovative science, technology, and engineering (ST&E) of the scale expected of a national laboratory—the hallmark of Livermore since its inception. As a premier, national-security laboratory, Livermore advances ST&E to ensure

the safety, security, and reliability of the U.S. nuclear deterrent; reduce threats to national and global security; enhance the nation's energy and environmental security; and strengthen the nation's economic competitiveness.

## Big, Audacious Goals

From its earliest days, the Laboratory has distinguished itself by aiming at “big, audacious goals,” or BAGs. BAGs arise from innovative thinking about the future, considering both national needs and game-changing breakthroughs in ST&E to meet those needs. They are central to Livermore's approach to carrying out its missions and are aligned with Laboratory core values such as “passion for mission,” “intense competition of ideas,” “teamwork while preserving individual initiative,” and “balancing innovation with disciplined execution.” BAGs often arise seemingly spontaneously, but they depend on senior management leadership to

Stockpile Stewardship



Global Security



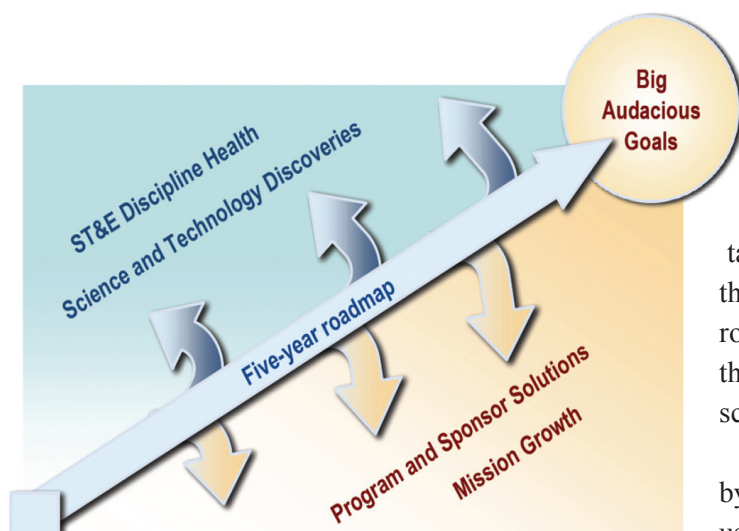
Energy & Environment



Basic Science



Our five-year investment roadmap derives from LLNL's vision: Pursuing global security through the application of multidisciplinary ST&E to enhance national security, meet energy and environmental needs, and enhance economic competitiveness.



Our five-year roadmap will focus on defining big audacious goals for a set of core strategic thrusts. It will enable us to incrementally deliver new products to programs and sponsors along the way, therefore ensuring continued success in the Laboratory's missions.

benefit from institutional investments, establish roots, and blossom into programs.

### The 100-Day Study

Led by Tómas Díaz de la Rubia, Laboratory Chief Research and Development Officer, the 100-day study was launched to closely examine a collection of ideas for BAGs that meet critical national needs and are aligned with core strategic mission thrusts of the Laboratory. The aim was to refine the definition of each BAG and develop a five-year roadmap for investments necessary to achieve the goals and position Livermore as an ST&E leader in the mission area. The roadmaps integrate consideration of ST&E strategies (including leap-ahead goals), external strategies (including program development, business development, and strategic alliances), and capability strategies (including investments in people, facilities, and infrastructure).

Director George Miller, together with the Laboratory senior management team, has identified seven strategic mission thrust areas summarized in the following section. In each area the BAG aims to make game-changing, disruptive contributions to

major national needs that are clear, believable, and inspiring. The roadmaps provide input to Livermore senior managers to make institutional investment decisions. In addition, an ST&E crosscutting team was tasked to ensure alignment of ST&E capabilities with the strategic mission thrusts. This team also developed a roadmap identifying areas of foundational ST&E where the Laboratory can develop new capabilities that advance scientific discovery and enable future missions.

The outcome is an actionable plan that, as approved by the Director and LLNL senior management, will be used to direct the Laboratory's investment and workforce strategy for the future. All seven areas are strategic priorities of the Laboratory and will receive institutional support; work will be accelerated in selected areas with greater support than they have received to date. Mechanisms will be established to track progress and modify strategies as appropriate.

This document provides a short summary of input material provided in the roadmaps. These summaries preferentially emphasize national need, Livermore's role



Aiming to meet the enduring and emerging national needs, our five-year investment roadmap builds on a set of core strategic mission thrust areas that will position the Laboratory as a leader and number-one partner for our national-security missions.

in meeting the need, and primarily ST&E considerations. Not all goals and plans emerged from the 100-day study will be achievable as expeditiously as proposed because they are closely linked with the deliberate, ongoing process of institutional investment decisions and pending federal budget decisions. The path forward at the conclusion of the 100-day study is also described.

## Core Strategic Mission Thrust Areas

The seven thrust areas depend on and reinforce the Laboratory's key ST&E strengths and unique capabilities, which derive from mission responsibilities. Progress in these areas will meet important national needs, and the underpinning investments in ST&E will provide Livermore new capabilities to meet national needs that might emerge in coming decades.

Study team leaders were selected for each area and the teams assembled. Both a steering committee, chaired by Greg Suski, and a formal red team, led by C. Bruce Tarter, reviewed the work of the study teams. A brief summary of the seven core mission thrust areas follows.

## Stockpile Stewardship Science

<b>Big, Audacious Goal</b>	Provide high confidence in the reliability of a U.S. nuclear stockpile that is intrinsically safe and secure.
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*Team leaders: Charlie Verdon and Robert Canaan*

A smaller nuclear deterrent demands a heightened level of confidence in the safety, security, and reliability of each weapon. This challenges traditional approaches to sustaining stockpile confidence. Our big, audacious goal requires significant advances in ST&E: embedded sensors to provide persistent surveillance; safety, security, and use control technology for "intrinsically" safe and secure warheads; understanding weapons boost physics, a process in the functioning of modern nuclear weapons; and increased rigor in uncertainty quantification for weapon certification. These advances by FY2015 will support the development and certification of intrinsic safety and security features and embedded sensors in anticipated upcoming stockpile life-extension programs.

## Nuclear Threat Elimination

<b>Big, Audacious Goal</b>	Eliminate the threat of nuclear attack by a rogue state or non-state actor.
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*Team leaders: Mike Carter and Mike Dunning*

Achieving the BAG requires breakthrough advances in ST&E targeted at gaps in current capabilities, which in turn, will attract a growing level of program support to the Laboratory. To improve global fissile material awareness, LLNL will improve standoff detection of significant amounts of nuclear materials and quantitative monitoring of reactor operations and other nuclear processes to prevent diversion. In addition, the Laboratory will develop technologies for rapid forensic analysis to provide the U.S. government an ability to attribute a nuclear threat or incident quickly. Development of cradle-to-grave materials-modeling capabilities will provide in-depth understanding and predictive capabilities to aid in analysis and nuclear defense planning.

## Cyber, Space, and Intelligence

<b>Big, Audacious Goal</b>	Global insight for decision dominance.
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*Team leaders: Wes Spain and Jim Trebes*

A fundamental transformation is needed to provide the intelligence community (IC) the decision advantage for 21st century national security. As the dependence on complex networks grows, gaps have arisen in the capability of the IC to exploit and defend complex networks. LLNL will lead development of a distributed approach to real-time situational awareness, with specific early application to the top national priorities of cybersecurity and space asset protection. Program-building in these areas will include development of predictive models and simulations, filling the major current inability to model or even understand the behavior of large-scale networked systems. In addition, LLNL will strengthen its enduring nuclear analysis support to the IC.

## Biosecurity

### Big, Audacious Goal

Rapid mitigation of evolving and unknown biothreats.

*Team leaders: Dave Rakestraw and Anantha Krishnan*

The U.S. is vulnerable to evolving and unknown pathogens. This gap calls for a flexible and agile biodefense strategy to counter bioterrorism, protect military forces, and meet public health needs. With cutting-edge analytical capabilities, LLNL will lead efforts in addressing this unmet security need by developing methods for rapid identification and characterization of existing, emerging, and unknown biothreats and by pursuing technologies for rapid development and deployment of medical countermeasures. These activities will leverage larger efforts in the biology/pharmaceutical community not focused on pathogens. Additionally, this area will focus on integrating intelligence with science-based threat characterization and risk analysis studies.

## Energy Security and Regional Climate Change

### Big, Audacious Goal

Predict, understand, and monitor climate and energy systems and deliver energy solutions while reducing atmospheric CO<sub>2</sub>.

*Team leaders: Doug Rotman and Jeff Roberts*

Confronting climate change—while simultaneously meeting demands for energy and water—is critical to national security, sustainable environmental quality, and economic health. As a recognized leader in the field, LLNL will pursue breakthroughs to better predict, understand, and monitor climate and energy systems on the regional scale, providing quantified uncertainties in climate predictions and integrated analyses to guide strategies for transforming the national energy system. LLNL will also become a recognized national center for wind power S&T, and the Laboratory will expedite deployment of underground coal gasification and carbon capture and sequestration. Creation of an open-campus

LLNL Climate Change and Energy Center will enable the wide range of partnerships necessary for success.

## LIFE (Laser Inertial Fusion Energy)

### Big, Audacious Goal

Provide a sustainable, once-through, closed fuel cycle nuclear energy option to provide >200 GWe for the nation by 2050.

*Team leaders: Erik Storm and Jeff Latkowski*

The challenge of meeting future energy needs while simultaneously decreasing dependence on fossil fuels is at the core of national security. LIFE represents a game-changing technology that would lead to sustainable, carbon-free energy that is safe, can drastically shrink the nation's and the world's inventories of nuclear waste, and minimizes national and international concerns over nuclear proliferation. In addition to achieving ignition and energy gain at the National Ignition Facility, several critical technology advances are needed for the first LIFE engine to be available by 2030. These include—among other challenges—low-cost, high-efficiency 10–20 MW diode-pumped, solid-state lasers; low-cost readily producible targets; and a system for target injection and laser intercept.

## Advanced Laser Optical Systems and Applications

### Big, Audacious Goal 1

Establish nuclear photo-science as an entirely new, “Nobel-quality” discipline to address national nuclear missions.

### Big, Audacious Goal 2

Become the nation's laser weapons science laboratory.

*Team leaders: Chris Barty and Craig Siders*

LLNL's unique knowledge and experience base in laser optical systems provide the foundation for bold steps to achieve two BAGs important to national security, creating the potential for nearly \$1 billion in new programs over the next decade. LLNL's mono-energetic gamma-ray (MEGa-ray) technology can provide a revolutionary leap in brightness capability that enables

new isotope-specific solutions to an astonishingly wide variety of critical and near-term national needs, such as the detection of highly enriched uranium—a grand challenge for homeland security. In addition, with its unique laser, computational, and experimental capabilities, LLNL can position itself to become the nation’s “laser weapons science laboratory” and realize the promise of speed-of-light weapons transforming the battlefield and strategic defense.

### ST&E Foundations and Crosscut Analysis

*Team leaders: Bill Goldstein, Dona Crawford, and Monya Lane*

The ST&E crosscut team interacted with the mission-thrust teams to understand their ST&E grand challenges. Altogether 18 “research directions” arose from the mission-thrust teams, and these research directions naturally fall into six crosscutting ST&E groupings, or “pillars”: controlling fusion and high-energy-density matter, high-performance computing and simulation, materials on demand, measurement science and technology, energy manipulation, and information systems.

For each of these foundational pillars, ST&E leap-ahead goals have been identified together with basic-science drivers. Roadmaps are being developed that articulate the pillars’ relationships to the mission thrusts and describe the institutional-investment and the business-development strategies. LDRD Exploratory Research investments within LLNL’s discipline directorates will support both the ST&E leap-ahead goals in the pillars and the basic science drivers.

### The Path Forward

Preparation of the roadmaps in each of the seven areas and their review by internal and external red teams have brought the 100-day study to a successful conclusion. The reviews have validated that the selected focus areas are indeed appropriate for this Laboratory at this time. The red teams commended the high quality of work but found variations in the maturity of the plans—particularly in the integration of S&T and business/program development objectives—largely due to the

compressed schedule. These differences will affect details about the path forward. For each area, the roadmaps will be “living documents,” subject to refinements and improvements as well as shifts in direction in response to technical progress and evolving national priorities.

The roadmaps will be used to provide a sharper focus to Laboratory investments over a five-year planning horizon and more effectively couple ST&E investments to business development and workforce/infrastructure plans. In particular, additional Strategic Mission Support (SMS) and Laboratory Directed Research and Development (LDRD) resources will move into the strategic focus areas.

Execution of a five-year integrated strategy requires extraordinary leadership and enduring commitment from Laboratory senior management. To this end, a governance structure is being established to ensure success of the five-year plan. The governance structure will consist of an Executive Investment Council, Strategic Councils, and (existing) External Review Committees:

- **Executive Investment Council**—consisting of the deputy director, the principal associate directors (PADs), and the chief research and development officer. This council will propose institutional budget allocations to the director, approve major changes to five-year plan, and terminate (where appropriate) ongoing focus areas and initiate new ones.
- **Four Strategic Councils** for *Nuclear Security*, *Homeland Security and Intelligence*, *Energy Security*, and *ST&E Foundations and Photon Missions*—chaired by a PAD and including a mix of PADs, associate directors, program directors, and discipline and program leaders. The councils will oversee execution of the five-year strategy and serve as change-control boards for roadmap plan. They will review yearly investment portfolios against the five-year plan and provide a forum for reviewing issues about the portfolio.
- **External Review Committees.** These committees will measure progress against stated roadmap milestones and goals, and they will evaluate the five-year plan in view of policy, program, and ST&E measures.

# Nuclear Threat Elimination

## Big, Audacious Goal

Eliminate the threat of nuclear attack by a rogue state or non-state actor.

Because of the wide spread of technology and knowledge about nuclear materials and nuclear weapons, the major obstacle to the acquisition of nuclear weapons capabilities for proliferant nations or terrorist groups is the production or acquisition of sufficient quantities of fissile materials to assemble a yield-producing device. Securing or eliminating the more than 2,000 metric tons of weapons-usable materials spread over more than a dozen countries is a daunting challenge. A defense-in-depth strategy is required to effectively reduce the risk of nuclear threat posed by rogue states or terrorists.

LLNL is positioned to play a leading role in an intensified effort by the Obama administration to reduce nuclear proliferation dangers. The Laboratory will build on successful R&D and operational-support activities across all aspects of a defense-in-depth strategy—providing intelligence-based assessments of adversaries; preventing proliferation at its source through denial, dissuasion, and deterrence; detecting proliferation activities and devising ways to counter those efforts; and responding to threatened or actual use of a nuclear device (including forensic analyses for attribution). The Laboratory is working with multiple sponsors, partnering with other laboratories, industry, and end-users and providing technical leadership in many areas.

Our goal is to provide S&T capabilities that will transform our nation's ability to eliminate the threat of nuclear attack by a rogue state or non-state-actor against U.S. interests. Many consider threat elimination intractable and speak of threat reduction. Eliminating the risk of a terrorist nuclear attack is too important to national security to be dismissed as too difficult—the nation's scientific expertise has yet to be fully focused on this goal. It is achievable through advances in S&T targeted at gaps in current capabilities, such as those

identified in an R&D roadmap for nuclear defense that was developed for the White House's Office of Science and Technology Policy. This initiative aims to address three major, long-term gaps in our nation's capabilities to eliminate the nuclear threat:

- **Global fissile material awareness**—having accurate knowledge of the location, quantities, and security status of weapons-usable materials worldwide.
- **Rapid forensics analysis**—providing the technical basis for the U.S. government to be able to attribute a nuclear threat or incident quickly and with high fidelity.
- **Cradle-to-grave materials modeling**—providing in-depth understanding and predictive capabilities throughout the lifecycle of fissile material and associated components of the fuel cycle and weaponization to aid in nuclear defense planning.

In each gap area, there are technical grand challenges that this initiative will address with leap-ahead S&T goals. Together, the targeted technical innovations would dramatically improve capabilities for detecting,



Antineutrino detectors can be a new tool to help international inspectors peer inside a working nuclear reactor.

securing, and eliminating weapons-usable materials worldwide. These innovations would also provide tested, timely analytical capabilities for responding to a nuclear incident and attributing the source of nuclear materials in the event of a successful theft, smuggling, or use.

The following summarizes the key S&T leap-ahead goals in the three gap areas:

### Global Fissile Material Awareness

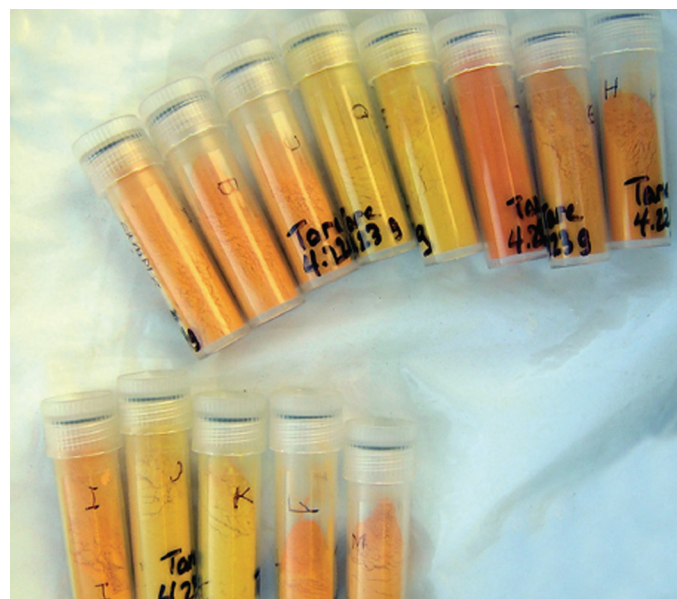
- Standoff detection of significant quantities of fissile material—extending the detection range from tens of meters to 1 kilometer or even low-earth orbit, utilizing visible fluorescent signatures from cosmic-ray-induced fission reactions.
- Quantitative monitoring of reactor operations—extending the range of LLNL-pioneered antineutrino monitoring of plutonium production in nuclear reactors to one to hundreds of kilometers standoff, revolutionizing the global nonproliferation regime.
- Quantitative monitoring of nuclear processes to prevent diversion—improving gamma-ray and neutron detection for monitoring nuclear processes to  $\pm 2\%$  precision to ensure no diversions of significant quantities of fissile materials.

### Rapid Forensic Analysis

- Fieldable, autonomous, quantitative forensic collection and analysis techniques—providing at least a ten-fold increase in speed, fidelity, and capability across the spectrum of nuclear terrorism threats, delivering analysis results within 24 hours.
- Validated physical models of actinide chemistry and speciation—providing heretofore unavailable data on actinide volatility at extreme conditions, needed for high-fidelity attribution after a nuclear event.

### Cradle-to-Grave Materials Modeling

- Predictive physical models of key properties of all significant fissile material production processes—providing, in concert with forensics, the technical basis for quickly reconstructing or extrapolating from a nuclear incident.
- Validated nuclear burn and condensation codes—extending mature capabilities for modeling



To track illicit nuclear materials to their sources, forensic scientists require autonomous, real-time fieldable techniques to address a wide spectrum of nuclear threats.

performance of U.S. designs to different types of designs, including improvised nuclear devices, and the interactions with render-safe options.

- Integrated end-to-end modeling capability for threat assessment, forensics, and emergency response—providing rapid, integrated assessments.

These leap-ahead S&T goals in this initiative build on LLNL's long-standing competencies in nuclear design, intelligence, sensor development, and forensic science. Roadmaps have been developed that integrate S&T goals, internal investments, and anticipated business growth. Success requires sustained internal investments in high-performance computing at the necessary classification level, modernization of forensic science capabilities, and a modern accelerator and detector development laboratory. These capabilities will result in expanded R&D opportunities with departments of Energy, Homeland Security, and Defense and the intelligence community. The estimated budgets for the organizations within these departments that have specific responsibilities for nuclear counterterrorism and nonproliferation are expected to grow by about \$1 billion by FY2015.

# Stockpile Stewardship Science

## Big, Audacious Goal

Provide high confidence in the reliability of a U.S. nuclear stockpile that is intrinsically safe and secure.

Nuclear weapons will remain essential to U.S. national and international security for decades to come. However, the nation's nuclear stockpile will grow smaller, demanding a heightened level of confidence in stockpile safety, security and reliability, ideally to the level of each individual weapon. A small stockpile—in addition to the absence of nuclear testing—challenges traditional approaches to sustaining confidence.

Since the end of nuclear testing, the Stockpile Stewardship Program (SSP) has been the nation's approach to maintaining confidence in its nuclear deterrent. SSP has been successful to date. However, significant issues are beginning to crop up in a continually aging stockpile, and some difficult new challenges arise from stockpile size reduction and changing world threats. As the stockpile size shrinks, we lose the ability to rely on redundancy in deployed systems and weapons in inactive reserve to bolster overall confidence and hedge against unanticipated problems. The importance greatly increases in our knowledge and accurate assessment of each weapon. Smaller numbers ratchet up the burden on the design and science, technology, and engineering (ST&E) competency and capabilities at the laboratories and plants to sustain confidence in the deterrent.

SSP must take its next big step. Our big, audacious goal is to provide the nation high confidence in the reliability of a U.S. nuclear stockpile that is “intrinsically” safe and secure. This requires significant science and technology advances in four key areas, each of which we have identified as being a thrust area and a grand challenge:

- **Embedded sensors** to provide persistent surveillance and improve our knowledge of the specific state of each stockpiled weapon.

- **Safety, security and use control technology** to provide “intrinsically” safe and secure warheads that would be inoperable until the President's order.
- **Weapon boost physics** to resolve key underlying unknowns associated with boost, the fusion ignition process that makes modern nuclear weapons work.
- **Uncertainty quantification** to increase the rigor of weapon certification and confidence in and the quality of annual stockpile assessments.

With key ST&E investments to accelerate progress, the Laboratory will be positioned to provide U.S. decision makers timely information about revolutionary technical options that provide a practical and cost-effective means for sustaining with high confidence a small stockpile of intrinsically safe and secure nuclear weapons. Past Livermore innovations have resulted in today's stockpile, and as in the past, the Laboratory is thinking ahead to potential requirements stemming from evolving U.S. policy objectives. Researchers then strive to develop enabling technologies/systems that demonstrate proof-of-principle.

The four grand challenge areas present opportunities where innovations will define tomorrow's smaller stockpile. High-level leap-ahead goals have been identified for each area. These goals are driven by two even higher-level national program needs: ST&E capabilities to support the development and certification of intrinsic safety and security features into upcoming



Tiny sensors similar to the one shown here could be embedded in the nation's nuclear weapons to detect anomalies such as cracks or corrosion in weapon components.

life-extension programs by FY2015, and prototype demonstrations of embedded sensors capable of product realization by FY2018.

Success in Stockpile Stewardship Science will continue the Laboratory's long tradition of putting the national interest first and foremost, and it will reinforce the importance of Livermore in the nation's nuclear weapons program. But even success might not result in any increased funding from NNSA. For several areas, leap-ahead technical goals are synergistic with other thrust areas and important Laboratory missions, and program plans have been structured to enhance the potential for technology spin out and spin back. The five-year ST&E leap-ahead goals for the grand challenges and existing gaps include:

- **Embedded sensors** enable persistent surveillance of weapon systems, a necessary new paradigm for the stockpile of the future. Sensors would provide continuous, real-time monitoring of properties inside each weapon, allowing instantaneous detection of anomalies as well as trend tracking. Data would be indicative of aging and degradation, mechanical integrity, and exposure to harsh environments. The prototype sensors would accurately collect the required data. They can be inserted arthroscopically, have low power requirements, and do not result in safety or security holes.
- **Safety, security and use-control technology** presents challenges in the area of materials science. The timely introduction of new safety, security, and use-control technology necessitates the introduction of new materials, many of which have not been used previously in stockpile systems. Essential to success is the ability to assess and quantify the material aging and compatibility of potential technology candidates. This information is critical to enabling inclusion into the warhead, rigorous assessment of reliability, and warhead certification.
- **Weapon boost physics**, a highly complex process, is a major gap in current capabilities to predictively



Petascale computers such as Sequoia will be a key tool for uncertainty quantification to unravel known unknowns. Pictured here is a predecessor to Sequoia, Dawn, a 500-teraFLOPS IBM BlueGene/P system.

model modern weapon performance. Rigorously defensible assessments of boost performance require a validated understanding of the detailed microphysics of governing thermonuclear-burning plasmas. Predictive modeling is the foundation for confidence in the U.S. nuclear deterrent (and a smaller future stockpile) and certification of changes to weapons (including new safety and security features). Significant physics-knowledge gaps will be filled as well as gaps in diagnostics and target designs for experiments at the National Ignition Facility.

- **Uncertainty quantification (UQ)**, a newly emerging scientific field, is a central issue in predictive science through simulation using modern multiphysics simulation codes. Unprecedented computing power sets the stage for transformative breakthroughs in UQ that are applicable over many disciplines, particularly in stockpile stewardship and climate change. UQ is essential for making informed technical, programmatic, and policy decisions. A scientific and computationally rigorous approach to UQ is needed, as well as demonstration of UQ methodologies and analysis through comparison with experiments.

# Cyber, Space, and Intelligence

## Big, Audacious Goal

Global insight for decision dominance.

The “traditional” U.S. intelligence enterprise is unable to meet the demands placed on it by a world that is rapidly changing, rapidly expanding, and information-dense. Modern threats to the United States and its interests arise from adversaries (including individuals and small groups as well as nation states) operating within an unprecedented information and technology environment that provides them asymmetrical advantages. A fundamental transformation is necessary in order to counter those advantages and discover, access, and exploit intelligence information in a timely, secure manner. U.S. leadership requires actionable information—the decision advantage—for 21st century national security. Radical re-engineering of the country’s intelligence apparatus will be required if it is to become the globally networked and integrated intelligence enterprise called for in the Director of National Intelligence’s *Vision 2015* report.

As dependence on complex networks grows, gaps have arisen in the capability of the intelligence community (IC) to both exploit and defend complex networks. Three areas in particular are emerging as top national priorities:

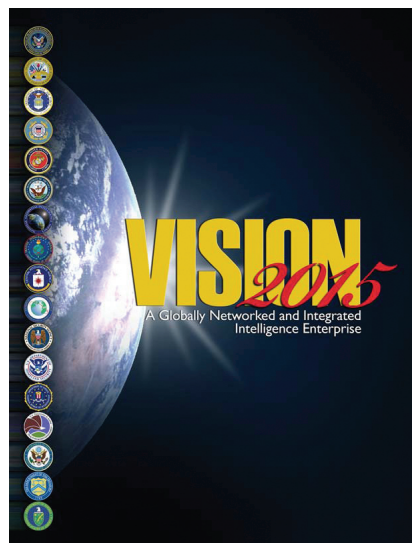
- **Cybersecurity.** Cybersecurity is a growing and rapidly evolving defense challenge. The White House’s Comprehensive National Cybersecurity Initiative is a large new program to greatly increase the security of government and military networks. While its main focus is on addressing known vulnerabilities, a larger R&D component looking at the future could be part of a commitment to increased investment in cybersecurity.
- **Space protection.** Until recently, the U.S. has enjoyed an asymmetric and relatively uncontested advantage in using space for high-value information gathering

and transmission. However, the situation is now rapidly changing. Protecting our freedom of operation in space has become a critical national priority, and a Space Protection Program has been launched jointly by the Department of Defense and the Office of the Director of National Intelligence (ODNI).

- **Intelligence analysis transformation.** Intelligence analysis must reach across the stovepipes and integrate information from multiple sources and results from multiple analytic methods. The ODNI has started a new Analytic Transformation Initiative to develop the required data standards, tools, and analytic methods needed for new crosscutting approaches.

Meeting these top national priorities requires a strong foundation of directed R&D, which the national laboratories are in a unique position to provide. LLNL is engaged in each of these areas—some projects in cooperation with other laboratories—and has established the following leap-ahead goals as part of this initiative to fill important gaps:

- **A distributed approach to real-time situational awareness.** The goal is to build a real-time model of a complex network’s states and behaviors. The



The nation is seeking a “globally networked and integrated intelligence enterprise” as stated in the *Vision 2015* report issued by the Office of the Director of National Intelligence.

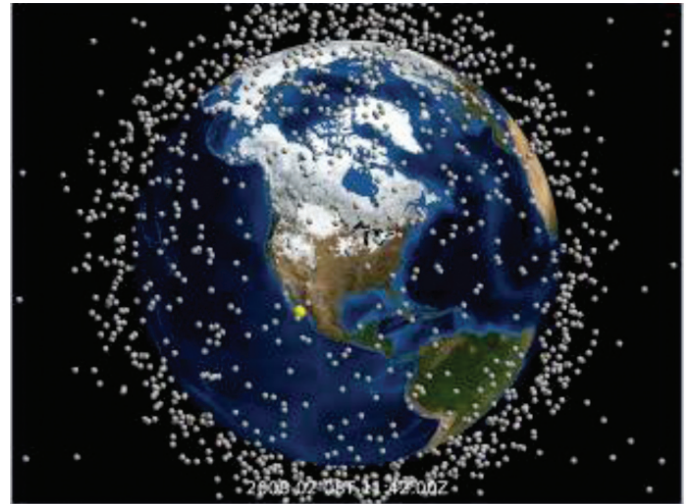
model (e.g., of space systems or cyber networks) can then be used to alert analysts to unusual behavior or determine the optimum data to collect to answer a question. The current paradigm of collecting data to a central repository where it is analyzed cannot scale to much larger systems. Rather, we must develop approaches to distributed data collection, distributed data models that live on the network, and analysis frameworks also distributed over the network.

- **Predictive models and simulations.** The current inability to model, simulate, or even understand the behavior of large-scale networked systems is a fundamental problem for developing new approaches to complex defensive and intelligence systems. Predictive and scalable simulations are important to the design and analysis of complex systems, such as space system protection (both physical and cyber) and large-scale cyberdefense, where full-scale experiments are not possible. Scalable simulation capabilities able to test and optimize defensive methods require R&D advances in many aspects of modeling and simulation.

Realizing these goals will require the Laboratory to invest in leadership, S&T capability, infrastructure, and workforce. Engagement is also an essential component of these plans, and LLNL will partner with other laboratories, academia and industry, and government sponsors. Our integrated S&T and program development strategy is supported by S&T investments in five specific areas of information science R&D, analytic environment enhancement, new facilities/capabilities, and workforce development.

In five years, these investments will position LLNL to lead a national partnership to transition to a net-centric intelligence enterprise. The Laboratory will be extending the frontiers of information science and will have demonstrated a prototype integrated intelligence environment. In addition, Livermore will serve as a national center, with high-end computing for intelligence simulation testing in support of broad IC needs, to serve as a focal point for emerging information and intelligence leaders in the IC.

Our program-development plans are organized into three major themes:



Protecting our operation in space has become a critical national priority. Predictive and scalable simulations, such as this visualization showing debris from an exploded satellite in the lower Earth orbit along with active satellites, are important to the design and analysis of space system protection and large-scale cyberdefense.

- **Solidify LLNL's base nuclear and WMD analysis programs.** Analysis of foreign nuclear (and other WMD) programs draws on deep expertise at the Laboratory in a range of scientific disciplines. To strengthen these efforts, we are working with the intelligence community to develop a Tri-Laboratory Nuclear Weapons Analysis Program while developing improved analysis tools.
- **Build technical leadership in emerging national priorities.** This initiative focuses on two of the most difficult S&T challenges to the intelligence community: cybersecurity and the critical need for protection of vital U.S. space assets.
- **Build a sustainable long-term intelligence focus area.** Solidifying our analytic base and establishing ourselves as technical leaders in key areas are critical to success. In addition, LLNL must renew our commitment to intelligence support as one of our principal contributions to the nation. This requires, in turn, a significant investment of internal resources, a deep commitment to partnering, superb programmatic execution, and high-caliber staff and leadership dedicated to advancing national intelligence goals.

# Biosecurity

## Big, Audacious Goal

Rapid mitigation of evolving and unknown biothreats.

Protecting the citizens of the world against emerging and currently unknown biothreats presents one of this century's greatest scientific challenges. Today, natural microbial evolution under the pressure of global human activity is the greatest source of such threats. However, the explosion of knowledge in life sciences and biotechnology is enabling humans to become masters at manipulating living systems—with this knowledge comes tremendous benefit and undeniable risk. The world's currently limited technical capability to rapidly detect, characterize and provide medical countermeasures to a previously unknown pathogen makes the human population extremely vulnerable.

Combining a strong core of bioscientists with the diverse engineering skills of the Laboratory, LLNL was the leader in starting the DOE Chemical and Biological Nonproliferation Program, which later became a central component of the biosecurity program at the Department of Homeland Security. The Laboratory has the opportunity to leverage recent successes in its biosecurity program, its breadth of bioscience-related S&T, and LLNL's historic excellence in nuclear security programs to gain even greater impact on addressing the growing needs for global biosecurity.

Our five-year roadmap defines a strategy to significantly expand the current biosecurity program and enable LLNL to be recognized as the premier national laboratory for biosecurity. LLNL will team with academia, industry, and other government agencies to anticipate and meet the challenges of mitigating the evolving biological threat. Specifically, the plan aims to meet the following grand challenges to providing biosecurity:

- ***Rapid detection and characterization of emerging and unknown threats***—with LLNL enabling a global disease surveillance system that will significantly

reduce the time it takes to detect and characterize an emerging or unknown pathogen.

- ***Speedier development of new medical countermeasures***—with LLNL dramatically reducing the time required to develop medical countermeasures for new pathogens by addressing key scientific barriers in the drug discovery and development process.
- ***Greatly improved science to underpin threat assessment and risk analyses***—with LLNL becoming the leading provider of biological risk analysis through science-based threat characterization, simulation, and intelligence.

Significant gaps exist in biosecurity S&T. For example, in genomics and proteomics, we ultimately need to be able to correlate specific genes to detailed functions. In instrumentation and assays, new approaches are needed for measuring thousands of targets with  $10^{10}$  dynamic range with micrometer and 1-second resolution. In host–pathogen science, much needs to be learned about pathogen invasion mechanisms, host response, metabolic pathways, and antibiotic resistance.



A system, such as the Autonomous Pathogen Detection System shown here, capable of continuously monitoring the environment for airborne biological agents can serve as an early warning system for civilians in the event of a terrorist attack.

Very importantly, multiscale computational tools are required for a wide range of applications.

The Laboratory's overall strategy will be to expand its strong position in biodetection, an area where LLNL has a proven track record and is already making strategic investments aimed at rapid-detection technologies. These efforts need to be sustained until a mature capability is available for national biodefense deployment. LLNL must also enhance its computational biology efforts, building on Laboratory strengths in scientific simulations, data management, and use of computational assets in the Terascale Simulation Facility. Other core institutional resources include biosafety level-3 facilities (for working with select agents), the Center for Accelerator Mass Spectrometry, the Micro-Fabrication Facility (for development of advanced microsensor technologies), and the Livermore Micro-Array Center. LLNL's special strengths in measurement science, microfabrication, bioinformatics, pathogen biology, and high-performance computing are key assets that we can offer to sponsor and bring to research partnerships.

The biosecurity plan, with three main thrusts, aims to deliver a number of discovery-class ST&E capabilities that are critical for program and mission growth. Some of these include autonomous and rapid processing of complex biological samples, single-microbe analysis and characterization, development of signatures corresponding to genetic modification and engineering, identification of virulence mechanisms, validated computational models for host-pathogen and host-drug interactions, and genome-to-structure-to function predictions. Each of these accomplishments will be of immense scientific value and suitable for publication in leading-edge biology, medical and biotechnology journals. The specific ST&E thrust areas are:

- **Advanced biochemical analysis tools and methodologies.** The focus will be on developing and demonstrating novel microfluidic and micro-array technologies for analysis of biological samples at the single microbe scale, new algorithms, and bioinformatics tools for identification of potential threat signatures. An important LDRD Strategic Initiative in this area is the Viral Discovery Platform, a demonstration of a rapid, autonomous, multiplexed



Multiplexed assays and proteomics research are helping the nation counter potential biothreats.

viral analyzer aimed especially at emerging and unknown threats. This capability currently does not exist in the scientific or biodefense community.

- **Host-pathogen interactions.** The focus will be on investigating various mechanisms of pathogenicity and the host response associated with infection, development of novel techniques to induce immunity to targeted threats, identification of drug targets for anti-infectives, and elucidation of metabolic and signaling pathways associated with host-pathogen and host-drug interactions. Both novel experiments and advanced computational models will be pursued to elucidate the multiscale phenomena associated with pathogen invasion and host response. These efforts—and those in computational and predictive biology described below—support the discovery of drug targets, drug design, and speedier development of medical countermeasures focus.
- **Computational and predictive biology.** The focus will be on the development of computational techniques and algorithms to simulate multiscale interactions associated with pathogen invasion and the binding of drugs with the host targets. Also of interest is the metabolic and signaling pathways that are triggered by these events. Another focus for the computational area is the development and validation of epidemiological models for human infections.



# Energy Security and Regional Climate Change Impacts

## Big, Audacious Goal

Predict, understand, and monitor climate and energy systems and deliver energy solutions while reducing atmospheric CO<sub>2</sub>.

Confronting climate change and its associated threats—while simultaneously meeting ever-accelerating demands for energy and water—is critical to national security, sustainable environmental quality, and continued economic health. It is a monumental challenge that can only be met through a spectrum of solutions, developed at multiple research institutions, widely implemented, and each contributing to the overall goal. The pursuit of solutions is a top priority of the Obama administration and the new Congress. The America Reinvestment and Recovery Act, for example, targets \$120 billion for energy and environmental programs and tasks. Now is a once-in-a-generation opportunity for the Laboratory to step up its contributions to meeting this challenge.

Some solutions that can contribute to meeting the energy security–climate change challenge are in areas where LLNL has special (often unique) skills and capabilities; others are in areas where the Laboratory is positioned to meet an important need by rapidly filling a gap in national expertise and pursuing a concept requiring leap-ahead science and technology (S&T). In particular, Livermore will pursue breakthroughs to better predict, understand, and monitor climate and energy systems. LLNL will also develop innovative technologies to reduce atmospheric CO<sub>2</sub> and provide clean energy. The establishment of two new research capabilities at the Laboratory, the Livermore Climate Change and Energy Security Center and an energy field laboratory at Site 300, will facilitate the international S&T collaborations in support of these important efforts.

LLNL has special capabilities and is providing S&T leadership in two nationally important areas that have the potential for substantial program growth:

## Regional Climate Change Prediction and Analysis

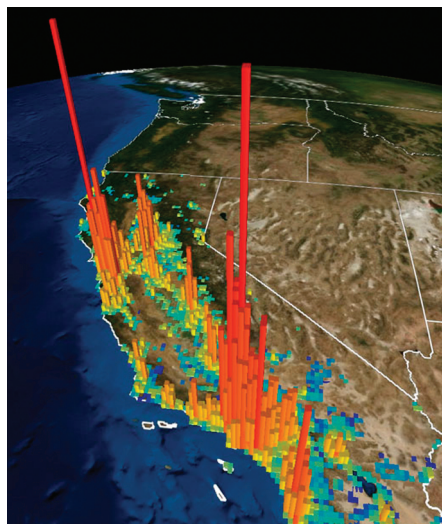
The Laboratory is combining its world-class capabilities in uncertainty quantification and climate-simulation analysis to dramatically improve our understanding of climate-change uncertainties and the key climate processes that drive uncertainty in climate prediction. We will focus our attention towards improved representation of physics in climate models and finally to improved climate predictions and understanding in systems critical to our national security. For example, with our unique capabilities in coupled climate and hydrology, we will assess climate change's impact on water resources and fresh water availability—critical to society, food production, and regional sustainability.

The goal is regional climate prediction and impact analysis with one-kilometer resolution and uncertainty quantification. These capabilities will provide the information needed by decision makers to formulate strategies for adapting to change, deploying advanced energy systems, and evaluating the risks of decisions. LLNL will also be positioned to provide technical leadership in the development of next-generation, high-resolution global climate analyses.

## Wind-Power Prediction

LLNL has world-class capabilities for modeling highly resolved wind flows over complex terrain and turbulence (e.g., to study stresses on turbine blades) as well as resources offered by the National Atmospheric Release Advisory Center (NARAC). LLNL researchers have tremendous insight into near-surface atmospheric flows. Our goal is to be the national solution provider for wind-energy deployment, simulation, and boundary-layer physics. LLNL capabilities can increase the output of existing wind farms (with high-fidelity predictions from a NARAC-like operation) and help site and increase the

Integrated analysis of regional energy systems, such as this sample distribution of California energy demand, can help re-shape national energy policy for the 21st century.



longevity of new farms. Experimental capabilities would be located at Site 300.

In addition, the Laboratory has special capabilities and is pursuing (or can rapidly grow) programs in four key “white-space” areas where there is no recognized national leader:

#### Energy Analysis and Regional Planning

The integration of high-resolution regional energy system models with climate predictions will help planners determine how best to inject new and cleaner technologies into existing systems. The U.S. lacks an integrated capability for the technical evaluation of the nation’s energy system to provide policy guidance. Nor is there an energy data center responsible for storing and analyzing data related to energy infrastructure or supplies. LLNL will concurrently create an energy analysis and regional energy-modeling system, building on recent relevant work and starting with a prototype representation of the Western energy system infrastructure.

#### Greenhouse Gas Emission Verification

Our goal is to become the leader in monitoring and verifying carbon emission reductions for international climate treaties. New tools and transparent mechanisms are needed to quantify CO<sub>2</sub> reductions in a region. LLNL will build on the NARAC expertise for modeling atmospheric transport and identifying

sources of observed emission. It will also employ the unique capabilities at the Center for Accelerator Mass Spectrometry—a leading facility for isotopic measurements—for high-precision, high-throughput analyses of radiocarbon to discriminate anthropogenic carbon emissions.

#### Underground Coal Gasification (UCG) and Carbon Capture and Sequestration (CCS)

LLNL is currently the U.S. leader in the UCG S&T area and among the leaders in CCS. Our goal is to serve as national technology leader for UCG through the application of world-class S&T in flagship demonstration projects and support for CCS deployment decisions. The Laboratory offers exceptional capabilities in simulation of UCG processes, reactive transport modeling, geophysical and geochemical monitoring, and geophysical experimentation as well as a successful track record working with UCG and CCS industrial partners. We aim to reduce the cost of CCS by 30% and accelerate deployment of both UCG and CCS by five to ten years.

#### Air Capture and Negative Emissions

High-risk, high-reward research will aim to “eliminate the problem” by finding ways to capture carbon from the air. The approach combines LLNL special capabilities in systems analysis and integration with the design and development of catalysts and new materials. Groundbreaking research in this area can create a new discipline, new industries, and define the maximum cost of climate change abatement.

As detailed in the prepared roadmap, effective partnerships with potential program sponsors, other research institutions, and industry are essential for success in S&T efforts and long-term program building. The Livermore Climate Change and Energy Security Center will facilitate many collaborations.

# LIFE (Laser Inertial Fusion Energy)

## Big, Audacious Goal

Provide a sustainable, once-through, closed fuel cycle nuclear energy option to provide >200 GWe for the nation by 2050.

The global demand for energy is expected to accelerate as billions of people move out of poverty and the size of the middle-class burgeons in countries such as China and India. The options to meet the demand on new energy sources are constrained by concerns of the effects of global warming and the need to severely cut back on anthropogenic CO<sub>2</sub> emissions. The U.S. currently consumes about 450 gigawatts of electric power (GWe), and by 2050, more than 500 new ~1-GWe plants may be required due to a combination of increased demand of a larger population, aging of current facilities, and the need to reduce dependence on carbon-based fuels. Renewables such as wind and solar energy can only partially fulfill the need; the same is true for fission energy, which carries the burden of managing disposition of spent fuel.

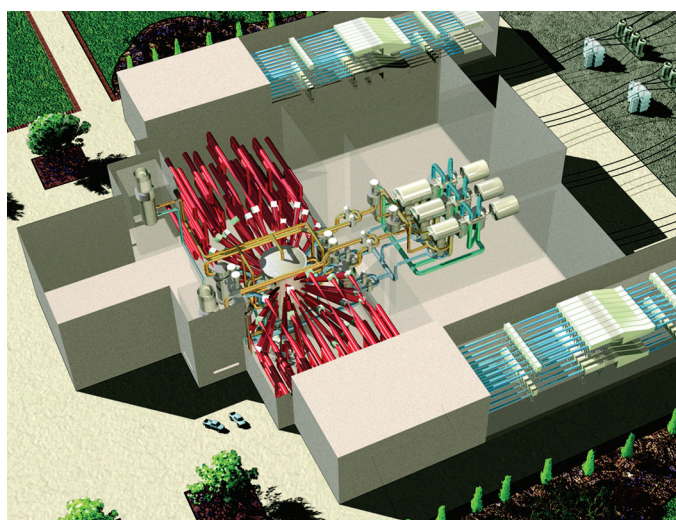
Fusion ignition and burn at the National Ignition Facility (NIF)—expected within the next couple years—will be a historic achievement and essential step toward making LIFE, short for Laser Inertial Fusion Energy, a reality. A revolutionary, breakthrough energy concept, LIFE has the potential to meet future worldwide energy needs in a safe, sustainable manner. It builds on the technology developed for NIF and promises safe, carbon-free, and sustainable energy. The technology offers many compelling advantages, either as a pure fusion energy source or as an engine that combines the best aspects of fusion and fission energy systems.

In specific, the design of a LIFE engine includes a 10- to 20-megawatt (MW) laser, pulsed to deliver ~1.4 megajoules (MJ) of energy 10 to 15 times per second. Fusion targets with energy gains of 25 to 35 produce about 350 to 500 MW of fusion power, which is converted to thermal energy by a lithium-based molten salt blanket. In addition, a LIFE engine can be

“charged” with fission fuel. The fusion neutrons would burn materials currently considered to be nuclear waste to produce electric power. As an example, a blanket consisting of 40 tons of depleted uranium or spent nuclear fuel in the form of pebbles would generate about 2.5 GWe, and the fuel could be used to more than 99% burn-up.

A LIFE power plant would generate gigawatts of power for as long as 50 years without refueling. The design is passively safe because no “critical mass” of nuclear materials would be present; there also would be no carbon dioxide emissions. Furthermore, LIFE eases nuclear proliferation concerns by disposing of long-term nuclear waste as it produces power. LIFE power plants operate with closed, self-contained once-through fuel systems and would produce 20 times less nuclear waste per unit of electricity than existing light-water reactors.

In order for commercial LIFE plants to be available in the 2030 timeframe, a LIFE integrated technology demonstration needs to be completed by the late 2010s, which would include a full-scale laser plant and subscale



The concept for a LIFE engine, illustrated here, would generate about 2.6 GW of energy. For commercial LIFE plants to be available in 2030, we must first establish technical/cost feasibility of LIFE's primary subsystems.



Significant development will be necessary to demonstrate target injection at the 15-Hz repetition rate with tracking, steering and low-power-laser engagement in relevant conditions. Shown here is a prototype injection system.

integrated demonstration of operation. Such a “pilot plant” demonstration would set the stage for a follow-on prototype power plant. This technically feasible, accelerated program calls for investments of tens of millions of dollars per annum over the next several years to establish the feasibility and cost of LIFE’s primary subsystems and prepare for the Technology Demonstration Program (TDP). The approach is feasible because the science, technology, and engineering (ST&E) building blocks for LIFE are logical and credible extensions of ignition on NIF and supporting materials and laser ST&E. In addition, the necessary near-term R&D for LIFE’s primary subsystems are inherently separable—they can be pursued as independent efforts. The TDP would require external funding of ~\$450 million plus ~\$275 million for construction of a LIFE-laser testbed, a “LIFElet”.

The focuses of the research over the first several years—setting the stage technically and making the case for LIFE programmatically—are the following:

- **National Ignition Campaign (NIC).** While NIC is programmatically supported and not formally part of the LIFE proposal, its success is paramount to LIFE moving forward. NIC plans include a credible attempt at ignition by 2010.
- **Laser technologies and test facility.** High-energy, high-average-power laser performance and reliability need to be demonstrated (including addressing the cost/manufacturability issue for the diode-laser pumps). LIFElet (7–10 kJ) and 2-3 watts (15 Hz) with a 20 × 40-cm aperture will serve as a testbed.

- **Target design and manufacturing.** Ignition will be demonstrated for LIFE-relevant targets with a robust 20- to 40-MJ yield. Mass production techniques will be explored to approach the cost of 30¢ per target.
- **Target engagement.** Target injection will be demonstrated at the 15-Hz repetition rate with tracking, steering, and low-power-laser engagement in relevant conditions.
- **Fuel materials and ultra-deep burn-up of materials.** Solid fissile-material fuel pellets must be designed and tested (experiments and simulations) to ensure performance (structural integrity, heat transfer, etc.). Solid hollow core designs show promise, and fabrication methods will be developed.
- **Structural materials.** First-wall materials must survive 5 to 10 years under intense exposure from fusion neutrons, x rays, and ions. OSD-ferritic steel and other options will undergo simulation studies and ion-beam irradiation testing.
- **Chamber environment.** In addition to first-wall survival, issues needing attention include rapid-clearing the chamber of debris, beam propagation, and damage to laser final optics. Scaled chamber-clearing and beam-propagation experiments will be performed, and options for final optics will be damage-tested.

While LIFE does not depend on fast ignition for success, the technology would allow the LIFE power plant to work with a smaller, less costly laser system. The possibility of incorporating fast ignition into the LIFE design will be explored. Other game-changing technologies that have broad application will also be studied.

By 2100, LIFE engines could power substantial fractions of the U.S. energy grid. LLNL is in a unique position to provide leadership and make LIFE a reality. The effort will engage many disciplines at the Laboratory and entail building a team of national collaborators at other DOE sites, U.S. industry, and major universities.

# Advanced Laser Optical Systems and Applications

Over the course of 50 years, LLNL has established itself as the leader in the development of high-energy and high-average-power lasers to meet critical national needs in mission areas such as laser-based isotope separation, inertial confinement fusion for security and energy applications, and high-energy-density science. Livermore's unique knowledge and experience base, which includes more than 35,000 person-years of activity, provides the foundation for bold steps to develop and apply laser optical systems to achieve two big, audacious goals—creating the potential for nearly \$1 billion of new programs over the next decade and additional opportunities for photon-based programs in the decades to follow.

## Big, Audacious Goal 1

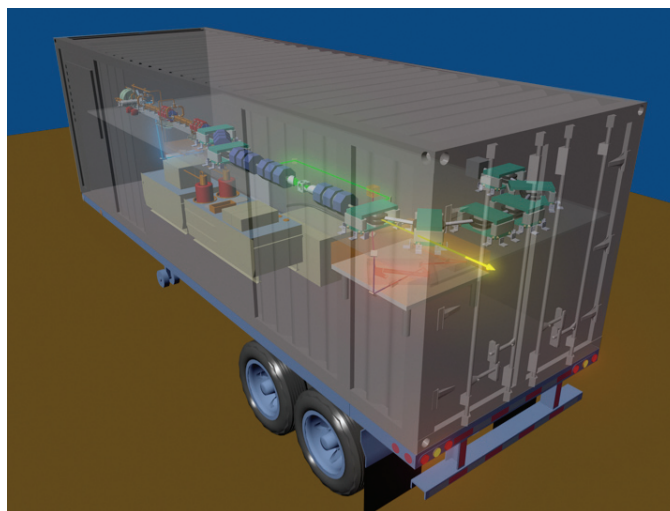
Establish nuclear photo-science as an entirely new, “Nobel-quality” discipline to address national nuclear missions.

Nuclear photo-science (the study of the nucleus with photons) is greatly advanced by a revolutionary concept developed and experimentally demonstrated by LLNL scientists over the last five years: the mono-energetic gamma-ray (MEGa-ray) source. Created by Compton scattering of short-duration laser pulses interacting with relativistic electrons, MEGa-rays are a new class of light source with extraordinary qualities. The peak brightness of a MEGa-ray pulse can be 15 orders of magnitude beyond any other man-made light in the mega-electron-volt spectral range. This revolutionary leap in brightness capability enables new solutions to an astonishingly wide variety of critical and near-term national needs:

- **Detection of high-enriched uranium (HEU) and HEU-based nuclear devices.** Detection of HEU, which can easily be shielded by a few millimeters of lead, is a grand challenge for homeland security. MEGa-ray is a game-changing technology. The Department of Homeland Security is showing keen

interest in MEGa-ray and contributing some funding toward its development.

- **Quantitative assay of nuclear waste (including imaging) and nuclear fuel and fuel systems.** MEGa-ray systems provide a leap-ahead technology for the billion-dollar-scale problems of precision assay of nuclear fuels and nuclear waste. It offers potential for more efficient use of fuels, less waste, better means for tracking materials of proliferation concern and for efficient, cost-effective means of waste cleanup and waste management.
- **Stockpile surveillance and stockpile science.** MEGa-ray systems can provide nondestructive high-resolution, 3D tomography images of stockpiled weapons to inspect for flaws and aging—a cost-saver and major benefit as the stockpile size shrinks. The technology can also be used for stockpile science applications, such as the study at high resolution (picoseconds and micrometers) of turbulent mixing.
- **Industrial nondestructive evaluation (NDE).** MEGa-rays provide the currently nonexistent capability



A field-ready prototype of the mono-energetic gamma-ray, or MEGa-ray, system represents a revolutionary leap in brightness capability that will address many critical national nuclear missions.

to look with photons at low-density objects that are obscured by high-density objects. The NDE enterprise worldwide is worth billions of dollars.

- **Nuclear physics.** MEGa-rays have the potential of revitalizing nuclear physics research, and Livermore, with a users' facility, could serve as a magnet for groundbreaking research.

Growth of MEGa-ray-based programs starts with internal investments to develop an onsite, compact MEGa-ray capability, which will provide the base technical platform to conduct detailed proof-of-principle detection, imaging and assay experiments. It is anticipated that external sponsors will more than double the internal investments in upgrades to the base machine to address their specific mission requirements. Laboratory studies will provide the technical basis for developing sponsor-specific advanced technology demonstrators, which if successful will provide the basis for development of production prototypes, transfer of technology to industry, and deployment in the field.

**Big,  
Audacious  
Goal 2**

Become the nation's laser weapons science laboratory

The promise of speed-of-light laser weapons to transform battlefield and strategic defense is long standing and as yet unmet. Chemical lasers have been unable to meet the combined requirements of megawatt-class power, near-perfect beam quality and acceptable battlefield logistics. Weapons systems based on LLNL's pioneering electric laser technologies can meet these requirements and provide prime opportunities for LLNL to both transform the billion-dollar Department of Defense (DoD) laser weapons enterprise and to grow new DoD programs.

Our plan aims to establish LLNL as the nation's "laser weapons science laboratory" and in doing so transform the laser weapons enterprise of the 21st century. Like the nuclear weapons enterprise of the 20th century, it requires an end-to-end approach: weapon design; production engineering for specific applications and customers; experimentally validated, first-principles understanding of weapon lethality and vulnerability; and



Weapons systems based on LLNL's pioneering electric laser technologies can provide prime opportunities for LLNL to transform the laser weapons enterprise.

diligent evaluation and prediction of the emergence of potential threats.

There is no current entity that can be considered as the nation's laser weapons science laboratory, and the strategy for positioning LLNL to become it requires coordinated growth of laser weapons projects and related laser weapons activities. The plan combines internal S&T investments over five years and targeted changes in the way LLNL engages DoD sponsors and their laboratories. In addition to increased face-to-face interactions, it is important to establish a high-level agreement with DoD that formalizes interactions. Expected to generate \$100 million in new programs over the next five years, the plan includes three main S&T thrusts:

- **Electric laser development.** LLNL will continue to grow existing DoD-funded efforts in the tailored-aperture ceramic laser and diode-pumped alkali laser, while internally investing in new capabilities in high-average-power fiber lasers and ceramic materials technology.
- **Laser lethality and vulnerability.** A full science-based understanding of laser weapons effects does not currently exist. LLNL will invest in developing a first-principles, experimentally validated, multiscale physics model of laser lethality and vulnerability that accounts for all critical interactions.
- **International assessments.** LLNL will develop an intelligence database and team that collect and analyze information to provide assessments and projections of the worldwide status of high-average-power lasers and threats.

# Science, Technology, and Engineering (ST&E) Foundations

ST&E Pillars	Fusion and High-Energy-Density Matter	High-Performance Computing and Simulation	Materials on Demand	Measurement Science and Technology	Energy Manipulation	Information Systems
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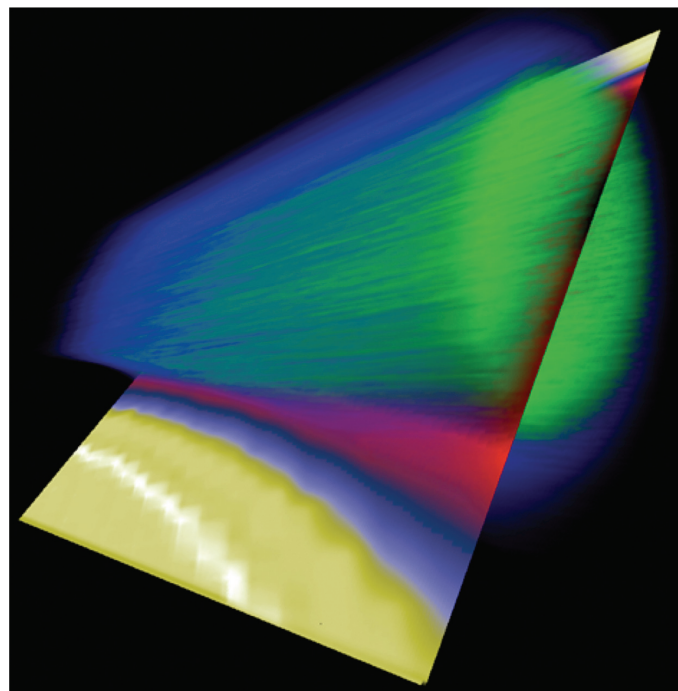
Cutting-edge ST&E underpin success in LLNL's important national security missions. Our outstanding workforce, unique facilities, and multidisciplinary team-science approach to problem-solving enables Livermore to anticipate emerging national needs, devise innovative ST&E solutions, and deliver to sponsors products that meet their most challenging needs. Sustained mission success requires continual reinvestment in ST&E to keep the Laboratory vital and attract the best and brightest to Livermore. A strong foundational science and engineering base provides the Laboratory the ability to seize program opportunities, the agility to react quickly to technical surprises, and the flexibility to respond to programmatic changes.

Important products of the 100-day study are the five-year roadmaps developed in each of seven mission thrust areas. Analyses conducted by the ST&E team served to validate, cross-index, and identify commonalities among the thrust-area teams' research directions and their ST&E grand challenges they identified. Altogether 18 research directions arose from the mission-thrust teams. The team found that these research directions naturally fell into six crosscutting ST&E groupings, or pillars. The pillars and their associated goals are:

- **Controlling fusion and high-energy-density (HED) matter**—control burning plasmas and develop an integrated and predictive understanding of HED matter.
- **High-performance computing and simulation (HPC&S)**—make possible system-focused simulation with confidence on the next decade's computing environments with more than one million processor cores.

- **Materials on demand**—accelerate the discovery of new materials for HED science, burning plasmas, fusion energy science, and advanced energy systems.
- **Measurement science and technology**—diagnostics able to view complex, highly energetic dynamic processes in 3D with sub-picosecond, sub-nanometer resolution.
- **Energy manipulation**—reduce accelerator footprints by three orders of magnitude at fixed energy.
- **Information systems**—rapidly discover emergent behaviors from complex information systems with quantifiable confidence.

For each of these pillars, the crosscut team identified the basic science drivers and ST&E leap-ahead goals.



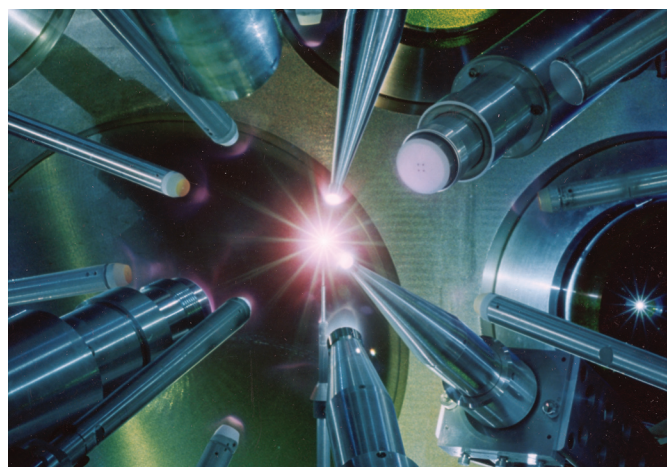
High-performance computing and simulation is a key element in essentially all of the mission thrust areas.

Roadmaps are being developed that articulate the support each pillar provides to the mission thrusts and describe the institutional investment and business development strategies. The aims are to ensure success in current programs, enable the identified mission thrusts, support discovery-class science, and provide the nation with unique research capabilities.

The combination of ST&E pillars and strategic mission thrusts makes clear the importance of the multidisciplinary approach to mission-directed research and development at the Laboratory, fully integrating experiments, simulations, basic science, and engineering disciplines. Also evident is the dominating importance in both mission and ST&E of the unique, internationally preeminent capabilities of the Laboratory. In particular, LLNL leadership in high-performance computing and simulation underpins each mission-thrust area. Similarly, combining complementary ST&E strengths with mission thrusts that depend on mastering fusion will position LLNL to be the nation's fusion laboratory.

For example, *controlling fusion and HED matter* is an essential ST&E pillar to enable LLNL as the nation's fusion laboratory, while at the same time it is key to mission thrusts in stockpile stewardship science, nuclear threat elimination, Laser Inertial Fusion Energy (LIFE), and advanced laser optical systems and applications. The control of burning plasmas—a big, audacious goal of the pillar—will enable optimization of the performance of fusion-energy concepts to make them practical, affordable sources of clean energy. Grand challenges include achieving ignition and fast ignition on NIF, exploring new fusion concepts, developing advanced diagnostics, and achieving a fundamental understanding and predictive capability of the control of burning plasmas. A predictive capability is critical to the success of stockpile stewardship and fusion energy.

Development of a predictive capability places exceeding high demands on the *HPC&S* pillar. Much greater computational capacity and capability will be needed for complex, multiphysics, multiscale simulations and uncertainty quantification to fully transform simulations into predictive science tools. New technologies will be required to scale HPC system



Several of the mission areas combine together to position LLNL as being the nation's "fusion laboratory," which draws on ST&E from each pillar.

hardware, software, networks, and storage systems up to 100 times current capability. Other grand challenges include the development of scalable tools, libraries, and programming models to rapidly build/test applications for 1M+-core computing environments; stochastic methods and error analyses tools for uncertainty quantification; and highly usable simulation systems for multi-program efficiency and external adoption.

Both control of burning plasmas and a predictive understanding of HED matter demand advances from the *materials on demand* and *measurement science and technology* pillars. For example, new materials will be needed for the targets in NIF experiments, optical elements in inertial-confinement-laser systems, radiation-resistant first walls in LIFE and fusion-energy systems, and advanced diagnostics and detector systems for experiments. Experimental demands on measurement science will include high-precision metrology and material characterization (to ascertain "as-built" properties) and diagnostics able to view complex, highly energetic dynamic processes in 3D with subpicosecond, subnanometer resolution.

The experiments and simulations will generate enormous quantities of data that must be fused and analyzed to extract information. Grand challenges being addressed in the *information systems* pillar pertain to meeting these needs.

